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Spatiotemporal Imaging of Magnetization Dynamics at the Nanoscale

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Final Report

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The development of a table-top system to study the spatio-temporal dynamics of magnetic devices on fundamental scales to magnetism is of particular importance to engineering high performance spintronic memory and logic devices that are simultaneously high-speed, high-density, low-power, and radiation hard. Although ‘facility-based’ measurements at the scale of 50 nm and 100 ps are available using coherent synchotron sources (like the Advanced Light Source in Berkeley), a table topic system would enable high-throughput studies to develop the science and technology to support such high-performance spintronics. In this project we studied approaches to exceeding the diffraction limit for optical magnetic microscopy while still retaining the excellent temporal resolution that is accessible with pulsed lasers.

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Annual Report, AFOSR YIP grant # FA9550-12-1-0373, "Spatiotemporal imaging of magnetization dynamics at the nanoscale: Breaking the Diffraction Limit."

Abstract,

The development of a table-top system to study the spatio-temporal dynamics of magnetic devices on fundamental scales to magnetism is of particular importance to engineering high performance spintronic memory and logic devices that are simultaneously high-speed, high-density, low-power, and radiation hard. Although 'facility-based' measurements at the scale of 50 nm and 100 ps are available using coherent synchatron sources (like the Advanced Light Source in Berkeley), a table topic system would enable high-throughput studies to develop the science and technology to support such high-performance spintronics. In this project we studied approaches to exceeding the diffraction limit for optical magnetic microscopy while still retaining the excellent temporal resolution that is accessible with pulsed lasers.

July 2014

In the two years we've developed a careful understanding of the time-resolved anomalous Nernst effect (TRANE) as a platform for spatiotemporal imaging. The key question that we've focused on this year is: what is the true time resolution of this technique?

As a brief reminder, TRANE microscopy is a new method of imaging the in-plane component of magnetization that we've been developing, motivated by the idea that thermal interactions fundamentally have no far-field optical diffraction limit, and therefore they could in principle be pushed to very high spatial resolution by combining light with scannable nanoscale plasmon antennas. In TRANE microscopy, a vertical thermal gradient transduces an in-plane magnetic moment into an electrical voltage along the third mutually orthogonal direction.

The time resolution of TRANE microscopy comes of the lifetime of the thermal gradient induced by picosecond laser heating. The voltage generated in this effect only lasts as long as the thermal gradient, and thus we can either measure how long the voltage persists, or we can measure how rapid a variation of magnetization we can stroboscopically sample using this technique. Our initial approach was to make a direction measurement of the temporal duration of the TRANE voltage pulses coming from the sample. To do that, we performed electrical mixing experiments, were we send both the amplified TRANE pulse and an electrical reference pulse to an electrical mixer. Then we delay the electrical reference pulse in time relative to the TRANE pulse, which produces the temporal convolution of the two. From this we see that the TRANE pulse must be shorter than 80 ps, which is the shortest electrical reference pulse we can produce in our laboratory.

We also developed a finite-element model of the spatiotemporal thermal evolution in our samples. Thermal simulations show that the thermal gradient lifetimes are on the scale of 10 picoseconds, which while consistent with our results, are shorter than this approach will enable us to measure them. We have developed an experimental approach to measure this short time scale by directly measuring ferromagnetic resonance (FMR) using TRANE, which is much

higher frequency than we can experimentally measure by electrical mixing. We have made proof-of-concept FMR measurements using TRANE, but our current generation samples are not well enough impedance matched to our electrical detection circuit to measure FMR at high frequency.

We have also been characterizing the artifacts in TRANE microscopy. One of the artifacts looks like it will actually be a very useful tool for understanding dynamics of magnetization. In particular, we are able to make out both magnetic oscillations of our samples (at roughly 5 GHz) and oscillations that can be tracked back to the microwave current induced in the sample by the microwave antenna coupling inductively. This additional signal source can be understood by the fact that when we laser heat the sample, not only do we create a thermal gradient, but we also change the local resistivity of the sample. In the presence of a current, a voltage pulse is generated that we simultaneously measure in our experiment. We have developed a technique to separate these signals based on dual demodulation of the signal with respect to the laser chopping frequency and a small magnetic field modulations frequency.

In the future under our new AFOSR contract, we plan to fabricate a new generation of devices with appropriate impedance match to a 50 Ω transmission line to complete our FMR experiments. Furthermore, we plan to continue development of our numerical model so that we can quantitatively extract relevant thermal parameters from our experiment including the temperature change and the magnto-thermoelectric coefficient.

1.

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Abstract

The development of a table-top system to study the spatio-temporal dynamics of magnetic devices on fundamental scales to magnetism is of particular importance to engineering high performance spintronic memory and logic devices that are simultaneously high-speed, high-density, low-power, and radiation hard. Although 'facility-based' measurements at the scale of 50 nm and 100 ps are available using coherent synchatron sources (like the Advanced Light Source in Berkeley), a table topic system would enable high-throughput studies to develop the science and technology to support such high-performance spintronics. In this project we studied approaches to exceeding the diffraction limit for optical magnetic microscopy while still retaining the excellent temporal resolution that is accessible with pulsed lasers.

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